(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 042 822 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
26.05.2010 Bulletin 2010/21

(21) Application number: **98966753.0**

(22) Date of filing: **28.12.1998**

(51) Int Cl.:
H01L 41/08 *(2006.01)*

(86) International application number:
PCT/US1998/027669

(87) International publication number:
WO 1999/034453 (08.07.1999 Gazette 1999/27)

(54) PIEZOELECTRIC TRANSDUCER AND METHOD OF USE

PIEZOELEKTRISCHER WANDLER UND ANWENDUNGSMETHODE

TRANSDUCTEUR PIEZO-ELECTRIQUE ET METHODE D'EMPLOI

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB IE IT LI NL PT SE

(30) Priority: **30.12.1997 US 553**

(43) Date of publication of application:
11.10.2000 Bulletin 2000/41

(73) Proprietor: **Remon Medical Technologies Ltd.**
38900 Caesarea Industrial Park (IL)

(72) Inventors:
- **DORON, Eyal**
  29500 Kiryat Yam (IL)
- **PORAT, Yariv**
  34367 Haifa (IL)
- **TSALIAH, Yoseph**
  27000 Kiryat Bialik (IL)

(74) Representative: **Pfenning, Meinig & Partner GbR et al**
Patent- und Rechtsanwälte
Joachimstaler Strasse 10-12
10719 Berlin (DE)

(56) References cited:

US-A- 4 064 375	US-A- 4 170 742
US-A- 4 535 205	US-A- 4 607 145
US-A- 5 160 870	US-A- 5 160 870
US-A- 5 381 067	US-A- 5 757 104

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 1 042 822 B1

Description

[0001] The present invention relates to an acoustic transducer and, in particular, to a miniature flexural piezoelectric transducer for receiving acoustic energy transmitted from a remote source and converting such energy into electrical power for activating an electronic circuit. Further, the present invention relates to a miniature flexural piezoelectric transmitter for transmitting acoustic information by modulating the reflection of an external impinging acoustic wave.

[0002] The prior art provides various examples of piezoelectric transducers. Examples of such piezoelectric transducers are disclosed in U.S. Pat. Nos. 3,792,204; 4,793, 825; 3,894,198; 3,798,473, and 4,600,855.

[0003] In a piezoelectric microphone or hydrophone according to US-A-4535205 the elastic structure which reacts directly to the acoustic pressure is formed of piezo-electric polymer. The electroacoustic transducer according to the invention makes use of an elastic structure in the form of a rim clamped plate having at least one incurvation and covered on at least one of its two faces with electrodes connected to an impedance-matching circuit.

[0004] An electro-acoustic transducer according to US-4,064,375 has a piezo-electric film polymer diaphragm which is dressed to a part spherical surface and the periphery of which is clamped. Electrodes placed over the surface of the diaphragm apply an electric field transverse the plane thereof which causes elongation parallel to the plane of the diaphragm. The rim of the diaphragm is mounted in a supporting framework which forms part of an enclosure isolating one side of the diaphragm from the atmosphere, The enclosure may be evacuated to improve the performance of the transducer by avoiding problems due to the formation of standing waves within the enclosure.

[0005] US 5,160,870 shows an ultrasonic sensing array having ultrasonic transducer elements formed on a micromachine single-crystal semiconductor wafer provided with a deep recess under each transducer. The sensing array discloses a composite (i.e. three layer) diaphragm to prevent buckling of the same and therefore does not concern a flexible or compliant piezoelectric layer which is usable in miniature transducers.

[0006] US 4,607,145 discloses a microphone transducer for use in a telephone including a piezoelectric diaphragm 30 covered on its two faces by electrodes. The diaphragm 30 is coupled at its periphery to a body 31 and to a metal spacer 40. A number of orifices in the body 31 and in a cap 35 connected to the body 31 serve as low-pass filters to cut off the frequency response of the diaphragm beyond 5 kHz. In use, the diaphragm is configured to resonate at a frequency of between 3.6 kHz to 4.4 kHz which, according to US 4,607,145, is suitable for telephone applications. None of the embodiments in US 4,607,145 disclose a microphone transducer having a resonance frequency determined by the physical dimensions of the transducer, and in which the wavelength of the external acoustic field is substantially larger than the physical dimensions of the transducer.

[0007] None of the prior art references provides a miniature flexural piezoelectric transducer specifically tailored so as to allow the usage of low frequency acoustic signals for vibrating the piezoelectric layer at its resonant frequency, wherein substantially low frequency signals herein refer to signals having a wavelength that is much larger than the dimensions of the transducer. Further, none of the prior art references provides a miniature transducer having electrodes specifically shaped so as to maximize the electrical output of the transducer. Further, none of the above references provides a transducer element which may be integrally manufactured with any combination of electronic circuits by using photolithographic and microelectronics technologies.

[0008] Further, the prior art fails to provide a miniature flexural piezoelectric transmitter which modulates the reflected acoustic wave by controllably changing the mechanical impedance of the piezoelectric layer according to a message signal received from an electronic component such as a sensor. Further, the prior art fails to provide such transmitter wherein the piezoelectric layer is electrically connected to a switching element, the switching element for alternately changing the electrical connections of the transmitter so as to alternately change the mechanical impedance of the piezoelectric layer. Further, the prior art fails to provide such transducer
wherein the mechanical impedance of the piezoelectric layer is controlled by providing a plurality of electrodes attached thereto, the electrodes being electrically interconnected in parallel and anti-parallel electrical connections. Further, the prior art fails to provide such transmitter wherein the piezoelectric layer features different polarities at distinct portions thereof Further, the prior art fails to provide such transmitter which includes a chamber containing a low pressure gas for enabling asymmetrical fluctuations of the piezoelectric layer. Further, the prior art fails to provide such transmitter having two-ply piezoelectric layer.

SUMMARY OF THE INVENTION

[0009] The present invention is of a miniature flexural transducer element, according to claim 1. Preferably, the cavity is etched into a substrate including an electrically insulating layer and an electrically conducting layer. The first electrode is preferably integrally made with a substantially thin electrically conducting layer, the electrically conducting layer being disposed on the substrate and connected thereto by a sealing connection. The cell member may be circular or hexagonal in cross section. According to further features in preferred embodiments of the invention described below, the substrate may include a plurality of cell members electrically connected in parallel or serial connections.

[0010] Preferably, at least one of the electrodes is specifically shaped so as to provide a maximal electrical output, wherein the electrical output may be current, voltage or power. A preferred shape of the electrodes includes two cores interconnected by a connecting member. A transducer element according to the present invention may also be used as a transmitter.

[0011] Preferably, the cavity of the transducer element includes gas of low pressure so as to allow its usage as a transmitter. According to the present invention there is further provided a transmitter element, comprising: (a) a cell element having a cavity; (b) a substantially flexible piezoelectric layer attached to the cell member, the piezoelectric layer having an external surface and an internal surface, the piezoelectric layer featuring such dimensions so as to enable fluctuations thereof at its resonance frequency upon impinging of an external acoustic wave; and (c) a first electrode attached to the external surface and a second electrode attached to the internal surface of the piezoelectric layer, the electrodes being electrically connected to an electrical circuit including a switching element for controllably changing the mechanical impedance of the piezoelectric layer. Preferably, the switching frequency of the switching element equals the frequency of an electrical message signal arriving from an electronic member, such as a sensor, thereby modulating a reflected acoustic wave according to the frequency of the message signal. The transmitter element may include a third electrode attached to the external surface and a fourth electrode attached to the internal surface of the piezoelectric layer. When using such a configuration, the switching element preferably alternately connects the electrodes in parallel and anti-parallel, thereby controllably changing the mechanical impedance of the piezoelectric layer. According to a specific configuration, the electrodes are interconnected by means of a built-in anti-parallel electrical connection. Alternatively, the electrodes may be interconnected by means of a built-in parallel electrical connection. The switching element may be an on/off switch. According to another embodiment, the piezoelectric layer includes first and second portions having opposite polarities. According to yet another embodiment, the transmitter element may include two cell members electrically interconnected by means of a built-in parallel or anti-parallel electrical connection. Alternatively, the switching element may alternately connect the cell members in parallel and anti-parallel electrical connections. The cell members may have piezoelectric layers of opposite polarities. According to yet another embodiment, the cavity of the transmitter element is covered by a two-ply piezoelectric layer including an upper layer bonded to a lower layer. The upper and lower layers may feature opposite polarities. The upper and lower layers may be separated by an insulating layer disposed therebetween. Further according to the present invention there is provided a method of transmitting acoustic information, according to claim 40 comprising: (a) providing a substantially flexible piezoelectric layer having first and second electrodes attached thereto, the piezoelectric layer being attached to a cell member, the electrodes being electrical connected to an electrical circuit including a switching element; (b) providing an acoustic wave for impinging on the piezoelectric layer, the acoustic wave having a reflected portion; (c) modulating the reflected portion of the acoustic wave by controlling the mechanical impedance of the piezoelectric layer, said controlling by switching the switching element at a frequency which equals the frequency of a message signal arriving from an electronic component such as a sensor. The method may further comprise: (a) providing third and fourth electrodes attached to the piezoelectric layer, the third and fourth electrodes being electrically connected to the electrical circuit; (b) changing the electrical connections between the electrodes by means of the switching element so as to change the mechanical impedance of the piezoelectric layer. According to a specific configuration, the first and second electrodes are attached to a first cell member and the third and fourth electrodes are attached to a second cell member.

The present invention successfully addresses the shortcomings of the presently known configurations by providing a miniature flexural piezoelectric transducer specifically tailored so as to allow the usage of low frequency acoustic signals for vibrating the piezoelectric layer at its resonant frequency, wherein substantially low frequency signals herein refer to signals having a wavelength that is much larger than dimensions of the transducer. Further, the present invention addresses the shortcomings of the presently known configurations by providing such transducer element having electrodes specifically shaped so as to maximize the electrical output of the transducer, and which may be integrally manufactured with any combination of electronic circuits by using photolithographic and microelectronics technologies.

Further, the present invention addresses the shortcomings of the presently known configurations by providing a miniature flexural piezoelectric transmitter which modulates a reflected acoustic wave by controllably changing the mechanical impedance of the piezoelectric layer according to a message signal received from an electronic component such as a sensor. Further, the present invention addresses the shortcomings of the presently known configurations by providing such transmitter wherein the mechanical impedance of the piezoelectric layer is controlled by providing a plurality of electrodes attached thereto, the electrodes being interconnected in parallel and anti-parallel electrical connections, and wherein at least a portion of the electrodes is electrically connected to a switching element, the switching element for alternately changing the electrical connections between the electrodes so as to alternately change the mechanical impedance of the piezoelectric layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1a is a longitudinal section of a transducer element taken along lines A-A in FIGs 2a-2e;
FIG. 1b is a longitudinal section of a transducer element taken along lines B-B in FIGs. 2a-2e;
FIG. 2a is a cross section of a transducer element taken along line C-C in FIG. 1a;
FIG. 2b is a cross section of a transducer element taken along line D-D in FIG. 1a;
FIG. 2c is a cross section of a transducer element taken along line E-E in FIG. 1a;
FIG. 2d is a cross section of a transducer element taken along line F-F in FIG. 1a;
FIG. 2e is a cross section of a transducer element taken along line G-G in FIG. 1a;
FIG. 3 shows the distribution of charge density across a piezoelectric layer of a transducer element resulting from the application of a constant pressure over the entire surface of the layer;
FIG. 4 shows the results of optimization performed for the power response of a transducer;
FIG. 5 shows a preferred electrode shape for maximizing the power response of a transducer;
FIG. 6 is a longitudinal section of another embodiment of a transducer element according to the present invention capable of functioning as a transmitter;
FIG. 7a-7f are schematic views of possible configurations of transmitters according to the present invention including parallel and anti-parallel electrical connections for controllably changing the mechanical impedance of the piezoelectric layer;
FIG. 8 is a longitudinal section of a transmitter element according to the present invention including an anti-parallel electrical connection; and
FIG. 9 is a longitudinal section of another embodiment of a transmitter element according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0013] The present invention is of a miniature flexural piezoelectric transducer for receiving acoustic energy transmitted from a remote acoustic radiation source and converting such energy into electrical power for activating an electronic circuit. Further, the present invention is of a transmitting element and method for transmitting information by modulating the reflection of an external impinging acoustic wave arrived from a remote transmitter.

[0014] The principles and operation of a transducer element according to the present invention may be better understood with reference to the drawings and the accompanying description.

[0015] Referring now to the drawings, FIGs. 1a, 1b and 2a-2e illustrate a preferred embodiment of a transducer element. As shown in the figures, the transducer element 1 includes at least one cell member 3 including a cavity 4 etched into a substrate and covered by a substantially flexible piezoelectric layer 2. Attached to piezoelectric layer 2 are an upper electrode 8 and a lower electrode 6, the electrodes for connection to an electronic circuit.

[0016] The substrate is preferably made of an electrical conducting layer 11 disposed on an electrically insulating layer 12, such that cavity 4 is etched substantially through the thickness of electrically conducting layer 11.

[0017] Electrically conducting layer 11 is preferably made of copper and insulating layer 12 is preferably made of a polymer such as polyimide. Conventional copper-plated polymer laminate such as Kapton™ sheets may be used for the production of transducer element 1. Commercially available laminates such as Novaclad™ may be used. Alternatively, the substrate may include a silicon layer, or any other suitable material. Alternatively, layer 11 is made of a non-conductive material such as Pyralin™.

[0018] Preferably, cavity 4 is etched into the substrate by using conventional printed-circuit photolithography methods. Alternatively, cavity 4 may be etched into the substrate by using VLSI/micro-machining technology or any other suitable technology.

[0019] Piezoelectric layer 2 may be made of PVDF or a copolymer thereof.
Alternatively, piezoelectric layer 2 is made of a substantially flexible piezoceramic. Preferably, piezoelectric layer 2 is a poled PVDF sheet having a thickness of about 9-28μm.

[0020] Preferably, the thickness and radius of flexible layer 2, as well as the pressure within cavity 4, are specifically selected so as to provide a predetermined resonant frequency. When using the embodiment of FIGs. 1a and 1b, the radius of layer 2 is defined by the radius of cavity 4.

[0021] By using a substantially flexible piezoelectric layer 2, the present invention allows to provide a miniature transducer element whose resonant frequency is such that the acoustic wavelength is much larger than the extent of the transducer. This enables the transducer to be omnidirectional even at resonance, and further allows the use of relatively low frequency acoustic signals which do not suffer from significant attenuation in the surrounding medium.

[0022] Prior art designs of miniature transducers, however, rely on rigid piezoceramic usually operating in thickness mode. In such cases the resonant frequency relates to the size of the element and speed of sound in the piezoceramic, and is higher by several orders of magnitude.

[0023] The present invention provides a transducer which is omnidirectional, i.e., insensitive to the direction of the impinging acoustic rays, thereby substantially simplifying the transducer's operation relative to other resonant devices. Such a transducer element is thus suitable for application in confined or hidden locations, where the orientation of the transducer element cannot be ascertained in advance.

[0024] According to a specific embodiment, cavity 4 features a circular or hexagonal shape with radius of about 200μm. Electrically conducting layer 11 preferably has a thickness of about 15μm. Cell member 3 is preferably etched completely through the thickness of electrically conducting layer 11. Electrically insulating layer 12 preferably features a thickness of about 50μm. The precise dimensions of the various elements of a transducer element according to the present invention may be specifically tailored according to the requirements of the specific application.

[0025] Cavity 4 preferably includes a gas such as air. The pressure of gas within cavity 4 may be specifically selected so as to predetermine the sensitivity and ruggedness of the transducer as well as the resonant frequency of layer 2.

[0026] As shown in FIG. 2b, an insulating chamber 18 is etched into the substrate, preferably through the thickness of conducting layer 11, so as to insulate the transducer element from other portions of the substrate which may include other electrical components such as other transducer elements etched into the substrate. According to a specific embodiment, the width of insulating chamber 18 is about 100μm. As shown, insulating chamber 18 is etched into the substrate so as to form a wall 10 of a predetermined thickness enclosing cavity 4, and a conducting line 17 integrally made with wall 10 for connecting the transducer element to another electronic component preferably etched into the same substrate, or to an external electronic circuit.

[0027] As shown in FIGs. 1a and 1b, attached to piezoelectric layer 2 are upper electrode 8 and lower electrode 6. As shown in FIGs. 2c and 2e, upper electrode 8 and lower electrode 6 are preferably precisely shaped so as to cover a predetermined area of piezoelectric layer 2. Electrodes 6 and 8 may be deposited on the upper and lower surfaces of piezoelectric membrane 2, respectively, by using various methods such as vacuum deposition, mask etching, painting, and the like.

[0028] As shown in FIG. 1a, lower electrode 6 is preferably made as an integral part of a substantially thin electrically conducting layer 14 disposed on electrically conducting layer 11. Preferably, electrically conducting layer 14 is made of a Nickel-Copper alloy and is attached to electrically conducting layer 11 by means of a sealing connection 16. Sealing connection 16 may be made of indium. According to a preferred configuration, sealing connection 16 may feature a thickness of about 10μm, such that the overall height of wall 10 of cavity 4 is about 20-25μm.

[0029] As shown in FIG. 2c, electrically conducting layer 14 covers the various portions of conducting layer 11, including wall 10 and conducting line 17. The portion of conducting layer 14 covering conducting line 17 is for connection to an electronic component such as a neighboring cell.

[0030] According to a preferred embodiment, electrodes 6 and 8 are specifically shaped to include the most energy-productive region of piezoelectric layer 2 so as to provide maximal response of the transducer while optimizing the electrode area, and therefore the cell capacitance, thereby maximizing a selected parameter such as voltage sensitivity, current sensitivity, or power sensitivity of the transducer element.

[0031] The vertical displacement of piezoelectric layer 2, Ψ, resulting from a monochromatic excitation at angular frequency ω is modeled using the standard equation for thin plates:

$$\left(\nabla^2 - \gamma^2\right)\left(\nabla^2 + \gamma^2\right)\Psi - \frac{3(1-\nu^2)}{2Qh^3}P + \frac{3iZ\omega\left(1-\nu^2\right)}{2Qh^3}\overline{\Psi} = 0$$

wherein Q is the Young's modulus representing the elasticity of layer 2; h the half-thickness of layer 2; ν is the Poisson ratio for layer 2; γ is the effective wavenumber in the layer given by: $\gamma^4 = 3\rho(1-\nu^2)\omega^2/Qh^2$, wherein ρ is the density of layer 2 and ω is the angular frequency of the applied pressure (wherein the applied pressure may include the acoustic pressure, the static pressure differential across layer 2 and any other pressure the transducer comes across) ; Z is the mechanical impedance resulting from the coupling of layer 2 to both external and internal media of cavity 4, wherein the internal medium is preferably air and the external medium is preferably fluid; P is the acoustic pressure applied to layer 2, and $\overline{\Psi}$ represents the average vertical displacement of layer 2.

[0032] When chamber 4 is circular, the solution (given for a single frequency component ω) representing the dynamic displacement of a circular layer 2 having a predetermined radius a, expressed in polar coordinates, is:

$$\Psi(r,\varphi) = \frac{I_1(\gamma a)\left[J_0(\gamma r) - J_0(\gamma a)\right] + J_1(\gamma a)\left[I_0(\gamma r) - I_0(\gamma a)\right]}{2h\rho\omega^2 L_0(\gamma a) + i\omega Z L_2(\gamma a)} P$$

$$L_0(z) = I_0(z)J_1(z) + J_0(z)I_1(z), \;\; L_2(z) = J_2(z)I_1(z) - I_2(z)J_1(z)$$

$$Z = \frac{P_A}{i\omega H_A} + i\left[\frac{4}{3\pi} + \frac{1}{6}\right]\omega\rho_W a$$

wherein:

$\Psi(r,\varphi)$ is time-dependent and represents the displacement of a selected point located on circular layer 2, the specific location of which is given by radius r and angle φ;
J and I are the normal and modified Bessel functions of the first kind, respectively; P_A, H_A are the air pressure within cavity 4 and the height of chamber 4, respectively; and ρ_W is the density of the fluid external to cavity 4.

[0033] The first term of the impedance Z relates to the stiffness resulting from compression of air within cavity 4, and the second term of Z relates to the mass added by the fluid boundary layer. An additional term of the impedance Z relating to the radiated acoustic energy is substantially negligible in this example.

[0034] The charge collected between electrodes 6 and 8 per unit area is obtained by evaluating the strains in layer 2 resulting from the displacements, and multiplying by the pertinent off-diagonal elements of the piezoelectric strain coefficient tensor, e_{31}, e_{32}, as follows:

$$Q(r,\varphi,t) = e_{31}\left(\frac{\partial\Psi}{\partial x}\right)^2 + e_{32}\left(\frac{\partial\Psi}{\partial y}\right)^2$$

wherein:

$Q(r,\varphi,t)$ represents the charge density at a selected point located on circular layer 2, the specific location of which is given by radius r and angle φ;
x is the stretch direction of piezoelectric layer 2; y is the transverse direction (the direction perpendicular to the stretch direction) of layer 2;
e_{31}, e_{32} are off-diagonal elements of the piezoelectric strain coefficient tensor representing the charge accumulated at a selected point on layer 2 due to a given strain along the x and y directions, respectively, which coefficients being substantially dissimilar when using a PVDF layer.
Ψ is the displacement of layer 2, taken as the sum of the displacement for a given acoustic pressure P at frequency f, and the static displacement resulting from the pressure differential between the interior and exterior of cavity 4, which displacements being extractable from the equations given above.

[0035] The total charge accumulated between electrodes 6 and 8 is obtained by integrating $Q(r,\varphi,t)$ over the entire area S of the electrode:

$$Q = \int_S Q(r,\varphi,t)\, d\bar{x}$$

[0036] The capacitance C of piezoelectric layer 2 is given by: $C = \frac{\varepsilon}{2h}\int_S d\bar{x}$,

wherein ε is the dielectric constant of piezoelectric layer 2; and 2h is the thickness of piezoelectric layer 2.

[0037] Accordingly, the voltage, current and power responses of piezoelectric layer 2 are evaluated as follows:

$$V = \frac{2h \int_S Q(r, \varphi, t)\, d\vec{x}}{\varepsilon \int_S d\vec{x}}, \quad I = 2i\omega \int_S Q(r, \varphi, t)\, d\vec{x}, \quad W = \frac{4ih \left[\int_S Q(r, \varphi, t)\, d\vec{x} \right]^2}{\varepsilon \int_S d\vec{x}}$$

[0038] The DC components of Q are usually removed prior to the evaluation, since the DC currents are usually filtered out. The values of Q given above represent peak values of the AC components of Q, and should be modified accordingly so as to obtain other required values such as RMS values.

[0039] According to the above, the electrical output of the transducer expressed in terms of voltage, current and power responses depend on the AC components of Q, and on the shape S of the electrodes. Further, as can be seen from the above equations, the voltage response of the transducer may be substantially maximized by minimizing the area of the electrode. The current response, however, may be substantially maximized by maximizing the area of the electrode.

[0040] FIG. 3 shows the distribution of charge density on a circular piezoelectric layer 2 obtained as a result of pressure (acoustic and hydrostatic) applied uniformly over the entire area of layer 2, wherein specific locations on layer 2 are herein defined by using Cartesian coordinates including the stretch direction (x direction) and the transverse direction (y direction) of layer 2. It can be seen that distinct locations on layer 2 contribute differently to the charge density. The charge density vanishes at the external periphery 70 and at the center 72 of layer 2 due to minimal deformation of these portions. The charge density is maximal at two cores 74a and 74b located symmetrically on each side of center 72 due to maximal strains (in the stretch direction) of these portions.

[0041] A preferred strategy for optimizing the electrical responses of the transducer is to shape the electrode by selecting the areas contributing at least a selected threshold percentage of the maximal charge density, wherein the threshold value is the parameter to be optimized. A threshold value of 0% relates to an electrode covering the entire area of layer 2.

[0042] FIG. 4 shows the results of an optimization performed for the power response of a transducer having a layer 2 of a predetermined area. As shown in the figure, the threshold value which provides an optimal power response is about 30% (graph b). Accordingly, an electrode which covers only the portions of layer 2 contributing at least 30% of the maximal charge density yields a maximal power response. The pertinent voltage response obtained by such an electrode is higher by a factor of 2 relative to an electrode completely covering layer 2 (graph a). The current response obtained by such electrode is slightly lower relative to an electrode completely covering layer 2 (graph c). Further as shown in the figure, the deflection of layer 2 is maximal when applying an acoustic signal at the resonant frequency of layer 2 (graph d).

[0043] A preferred electrode shape for maximizing the power response of the transducer is shown in FIG. 5, wherein the electrode includes two electrode portions 80a and 80b substantially covering the maximal charge density portions of layer 2, the electrode portions being interconnected by means of a connecting member 82 having a minimal area. Preferably, portions 80a and 80b cover the portions of layer 2 which yield at least a selected threshold (e.g. 30%) of the maximal charge density.

[0044] Any other parameter may be optimized so as to determine the shape of electrodes 6 and 8. According to further features of the present invention, only one electrode (upper electrode 8 or lower electrode 6) may be shaped so as to provide maximal electrical response of the transducer, with the other electrode covering the entire area of layer 2. Since the charge is collected only at the portions of layer 2 received between upper electrode 8 and lower electrode 6, such configuration is operatively equivalent to a configuration including two shaped electrodes having identical shapes.

[0045] Referring now to FIG. 6, according to the present invention chamber 4 of transducer element 1 may contain gas of substantially low pressure, thereby conferring a substantially concave shape to piezoelectric membrane 2 at equilibrium. Such configuration enables to further increase the electrical response of the transducer by increasing the total charge obtained for a given displacement of layer 2. The total displacement in such an embodiment is given by: $\Psi = P_0\Psi_{DC} + P\Psi_{AC} \cos \omega t$, wherein P_0 is the static pressure differential between the exterior and the interior of cavity 4; Ψ_{DC} is the displacement resulting from P_0; P is the amplitude of the acoustic pressure; and Ψ_{DC} the displacement resulting from P.

[0046] Accordingly, the strain along the x direction includes three terms as follows:

$$S_{xx} = \left(\frac{\partial \Psi}{\partial x}\right)^2 = P_0^2\left(\frac{\partial \Psi_{DC}}{\partial x}\right)^2 + P^2\left(\frac{\partial \Psi_{AC}}{\partial x}\right)^2 \cos^2 \omega t + 2P_0 P \frac{\partial \Psi_{DC}}{\partial x}\frac{\partial \Psi_{AC}}{\partial x} \cos \omega t$$

wherein the DC component is usually filtered out.

[0047] Thus, by decreasing the pressure of the medium (preferably air) within cavity 4 relative to the pressure of the external medium (preferably fluid), the value of P_0 is increased, thereby increasing the value of the third term of the above equation.

[0048] Such embodiment of the present invention makes it possible to increase the charge output of layer 2 for a given displacement, thereby increasing the voltage, current and power responses of the transducer without having to increase the acoustic pressure P. Further, such embodiment enables to further miniaturize the transducer since the same electrical response may obtain for smaller acoustic deflections. Such embodiment is substantially more robust mechanically and therefore more durable than the embodiment shown in FIGs. 1a and 1b. Such further miniaturization of the transducer enables to use higher resonance frequencies relative to the embodiment shown in FIGs. 1a and 1b.

[0049] Preferably, a transducer element 1 according to the present invention is fabricated by using technologies which are in wide use in the microelectronics industry so as to allow integration thereof with other conventional electronic components. When the transducer element includes a substrate such as Copper-polymer laminate or silicon, a variety of conventional electronic components may be fabricated onto the same substrate.

[0050] According to the present invention, a plurality of cavities 4 may be etched into a single substrate 12 and covered by a single piezoelectric layer 2 so as to provide a transducer element including a matrix of transducing cells members 3, thereby providing a larger energy collecting area of predetermined dimensions while still retaining the advantage of miniature individual transducing cell members 3. When using such configuration, the transducing cell members 3 may be electrically interconnected in parallel or serial connections, or combinations thereof, so as to tailor the voltage and current response of the transducer. Parallel connections are preferably used so as to increase the current output while serial connections are preferably used so as to increase the voltage output of the transducer.

[0051] Further, piezoelectric layer 2 may be completely depolarized and then repolarized at specific regions thereof so as to provide a predetermined polarity to each of the transducing cell members 3. Such configuration enables to reduce the complexity of interconnections between the cell members 3.

[0052] A transducer element according to the present invention may be further used as a transmitter for transmitting information to a remote receiver by modulating the reflection of an external impinging acoustic wave arrived from a remote transmitter.

[0053] Referring to FIG. 6, the transducer element shown may function as a transmitter element due to the asymmetric fluctuations of piezoelectric layer 2 with respect to positive and negative transient acoustic pressures obtained as a result of the pressure differential between the interior and exterior of cavity 4.

[0054] A transmitter element according to the present invention preferably modulates the reflection of an external impinging acoustic wave by means of a switching element connected thereto. The switching element encodes the information that is to be transmitted, such as the output of a sensor, thereby frequency modulating a reflected acoustic wave.

[0055] Such configuration requires very little expenditure of energy from the transmitting module itself, since the acoustic wave that is received is externally generated, such that the only energy required for transmission is the energy of modulation.

[0056] Specifically, the reflected acoustic signal is modulated by switching the switching element according to the frequency of a message electric signal arriving from another electronic component such as a sensor, so as to controllably change the mechanical impedance of layer 2 according to the frequency of the message signal.

[0057] Preferably, the invention uses a specific array of electrodes connected to a single cell member 3 or alternatively to a plurality of cell members so as to control the mechanical impedance of layer 2.

[0058] FIGs. 7a-7g illustrate possible configurations for controllably change the impedance of layer 2 of a transmitter element. Referring to FIG. 7a, a transmitter element according to the present invention may include a first and second pairs of electrodes, the first pair including an upper electrode 40a and a lower electrode 38a, and the second pair including an upper electrode 40b and a lower electrode 38b. Electrodes 38a, 38b, 40a and 40b are electrically connected to an electrical circuit by means of conducting lines 36a, 36b, 34a and 34b, respectively, the electrical circuit including a switching element (not shown) so as to alternately change the electrical connections of conducting lines 36a, 36b, 34a and 34b.

[0059] Preferably, the switching element switches between a parallel connection and an anti-parallel connection of the electrodes. A parallel connection decreases the mechanical impedance of layer 2, wherein an anti-parallel connection increases the mechanical impedance of layer 2. An anti-parallel connection may be obtained by interconnecting line 34a to 36b and line 34b to 36a. A parallel connection may be obtained by connecting line 34a to 34b and line 36a to 36b. Preferably, the switching frequency equals the frequency of a message signal arriving from an electrical component such as a sensor.

[0060] According to another embodiment (FIG. 7b), upper electrode 40a is connected to lower electrode 38b by means of a conducting line 28, and electrodes 38a and 40b are connected to an electrical circuit by means of conducting lines 27 and 29, respectively, the electrical circuit including a switching element. Such configuration provides an anti-parallel connection of the electrodes, wherein the switching element functions as an on/off switch, thereby alternately increasing the mechanical impedance of layer 2.

[0061] In order to reduce the complexity of the electrical connections, layer 2 may be depolarized and then repolarized at specific regions thereof. As shown in FIG. 7c, the polarity of the portion of layer 2 received between electrodes 40a and 38a is opposite to the polarity of the portion of layer 2 received between electrodes 40b and 38b. An anti-parallel connection is thus achieved by interconnecting electrodes 38a and 38b by means of a conducting line 28, and providing conducting lines 27 and 29 connected to electrodes 40a and 40b, respectively, the conducting lines for connection to an electrical circuit including a switching element.

[0062] According to another embodiment, the transmitting element includes a plurality of transducing cell members, such that the mechanical impedance of layer 2 controllably changed by appropriately interconnecting the cell members.

[0063] As shown in FIG. 7d, a first transducing cell member 3a including a layer 2a and a cavity 4a, and a second transducing cell member 3b including a layer 2b and a cavity 4b are preferably contained within the same substrate; and layers 2a and 2b are preferably integrally made (not shown). A first pair of electrodes including electrodes 6a and 8a is attached to layer 2, and a second pair of electrode including electrodes 6b and 8b is attached to layer 2b. Electrodes 6a, 8a, 6b and 8b are electrically connected to an electrical circuit by means of conducting lines 37a, 35a, 37b and 35b, respectively, the electrical circuit including a switching element so as to alternately switch the electrical connections of conducting lines 37a, 35a, 37b and 35b so as to alternately provide parallel and anti-parallel connections, substantially as described for FIG. 7a, thereby alternately decreasing and increasing the mechanical impedance of layers 2a and 2b.

[0064] FIG. 7e illustrates another embodiment, wherein the first and second transducing cell members are interconnected by means of an anti-parallel connection. As shown in the figure, the polarity of layer 2a is opposite to the polarity of layer 2b so as to reduce the complexity of the electrical connections between cell members 3a and 3b. Thus, electrode 6a is connected to electrode 6b by means of a conducting line 21, and electrodes 8a and 8b are provided with conducting lines 20 and 22, respectively, for connection to an electrical circuit including a switching element, wherein the switching element preferably functions as an on/off switch so as to alternately increase the mechanical impedance of layers 2a and 2b.

[0065] FIG. 7f shows another embodiment, wherein the first and second transducing cell members are interconnected by means of a parallel connection. As shown, electrodes 6a and 6b are interconnected by means of conducting line 24, electrodes 8a and 8b are interconnected by means of conducting line 23, and electrodes 6b and 8b are provided with conducting lines 26 and 25, respectively, the conducting lines for connection to an electrical circuit including a switching element. The switching element preferably functions as an on/off switch for alternately decreasing and increasing the mechanical impedance of layers 2a and 2b.

[0066] FIG. 8 shows a possible configuration of two transducing cell members etched onto the same substrate and interconnected by means of an anti-parallel connection. As shown in the figure, the transducing cell members are covered by a common piezoelectric layer 2, wherein the polarity of the portion of layer 2 received between electrodes 6a and 8a is opposite to the polarity of the portion of layer 2 received between electrodes 6b and 8b. Electrodes 8a and 8b are bonded by means of a conducting line 9, and electrodes 6a and 6b are provided with conducting lines 16 for connection to an electrical circuit.

[0067] Another embodiment of a transmitter element is shown in FIG. 9. The transmitter element includes a transducing cell member having a cavity 4 covered by a first and second piezoelectric layers, 50a and 50b, preferably having opposite polarities. Preferably, layers 50a and 50b are interconnected by means of an insulating layer 52. Attached to layer 50a are upper and lower electrodes 44a and 42a, and attached to layer 50b are upper and lower electrodes 44b and 42b. Electrodes 44a, 42a, 44b and 42b are provided with conducting lines 54, 55, 56 and 57, respectively, for connection to an electrical circuit.

Claims

1. A transducer element (1) for converting acoustic energy transmitted through an external fluid medium into electric energy comprising:

a cell member (3) having a cavity (4),
a substantially flexible piezoelectric layer (2) having a concave shape and being peripherally attached to said cell member (3) so as to isolate said cavity (4) from the external fluid medium, and such that a central portion of said flexible piezoelectric layer (2) being-non-supported and freely floats over said cavity (4),
said piezoelectric layer (2) having an external surface and an internal surface, said piezoelectric layer (2) featuring such dimensions so as to enable fluctuations thereof in-and-out of said cavity (4) at its resonance frequency upon impinging of an external acoustic field transmitted through the external fluid medium, and
a first electrode (8) attached to said external surface and a second electrode (6) attached to said internal surface,

the resonance frequency being determined by the physical dimensions of said transducer element (1), wherein the wavelength of the external acoustic field is substantially larger than the physical dimensions of said transducer element (1).

2. The transducer element of claim 1, wherein said cavity (4) is etched into a substrate (11,12).

3. The transducer element of claim 2, wherein said substrate (11,12) includes an electrically insulating layer (12) and an electrically conducting layer (11).

4. The transducer element of claim 3, wherein said first electrode (8) is integrally made with a substantially thin electrically conducting layer disposed on said substrate (11,12).

5. The transducer of claim 4, wherein said substantially thin electrically conducting layer (11) is connected to said substrate by means of a sealing connection (16).

6. The transducer element of claim 3, wherein said electrically insulating layer (12) is made of silicon.

7. The transducer element of claim 3, wherein said electrically insulating layer (12) is made of a polymeric material.

8. The transducer element of claim 5, wherein said sealing connection (16) is made of indium.

9. The transducer element of claim 1, wherein said piezoelectric layer (2) is made of PVDF.

10. The transducer element of claim 1, wherein said cavity (4) is circular in cross section.

11. The transducer element of claim 1, wherein said cavity (4) is hexagonal in cross section.

12. The transducer element of claim 2, wherein said substrate (11, 12) includes a plurality of cell members.

13. The transducer element of claim 1, wherein at least one of said first and second electrodes (8, 6) is specifically shaped so as to provide a maximal electrical output.

14. The transducer element of claim 13, wherein said electrical output is current.

15. The transducer element of claim 13, wherein said electrical output is voltage.

16. The transducer element of claim 13, wherein said electrical output is power.

17. The transducer element of claim 13, wherein at least one of said electrodes (8, 6) features first and second electrode portions (80a, 80b) interconnected by a connecting member (82).

18. The transducer element of claim 1, wherein said cavity (4) includes gas.

19. The transducer element of claim 18, wherein said gas is of substantially low pressure.

20. The transducer element of claim 19, wherein said transducer element (1) is used as a transmitter.

21. The transducer element of claim 19, further including a switching element electrically connected thereto so as to controllably change the mechanical impedance of said piezoelectric layer (2).

22. The transducer element of claim 1, wherein at least one of the first electrode (8) and the second electrode (6) includes a first portion (80a) and a second portion (80b) disposed on the piezoelectric layer (2), wherein the first and second portions (80a, 80b) are electrically connected by a connecting member (82).

23. The transducer element of claim 21, wherein the switching frequency of said switching element equals the frequency of an electrical message signal arriving from an electronic member.

24. The transducer element of claim 23, wherein said electronic member is a sensor.

25. The transducer element of clam 21, wherein said switching element is for modulating a reflected acoustic wave according to a message signal arriving from an electronic component.

26. The transducer element of claim 21, further including a third electrode (8b) attached so said external surface and a fourth electrode (6b) attached to said internal surface.

27. The transducer element of claim 26, wherein said switching element alternately connects said electrodes (8a, 8b, 6a, 6b) in parallel and anti-parallel connections, thereby controllably changing the mechanical impedance of said piezoelectric layer (2).

28. The transducer element of claim 26, wherein said electrodes (8a, 8b, 6a, 6b) are electrically interconnected by means of a substantially built-in anti-parallel connection.

29. The transducer element of claim 26, wherein said electrodes (8a, 8b, 6a, 6b) are electrically interconnected by means of a substantially built-in parallel connection.

30. The transducer element of claim 26, wherein said switching element is an on/off switch.

31. The transducer element of claim 26, wherein said piezoelectric layer (2) includes first and second portions (2a, 2b) having opposite polarities.

32. The transducer element of claim 20, wherein said transmitter element includes two cell members (3a, 3b).

33. The transducer element of claim 32, wherein said two cell members (3a, 3b) are electrically interconnected by means of a substantially built-in parallel connection.

34. The transducer element of claim 32, wherein said two cell members (3a, 3b) are electrically interconnected by means of a substantially built-in anti-parallel connection.

35. The transducer element of claim 32, wherein said switching element alternately connects said cell members (3a, 3b) in parallel and anti-parallel connections.

36. The transducer element of claim 32, wherein said cell members (3a, 3b) have piezoelectric layers (2a, 2b) of opposite polarities.

37. The transducer element of claim 19, wherein said cavity (4) is covered by a two-ply piezoelectric layer (50a, 50b) including an upper layer (50a) disposed on a lower layer (50b).

38. The transducer element of claim 37, wherein said upper and lower layers (50a, 50b) feature opposite polarities.

39. The transducer element of claim 37, further including an insulating layer (52) disposed between said upper and lower layers (50a, 50b).

40. A method of transmitting an acoustic information, comprising:

providing a substantially flexible piezo-electric layer (2) having a concave shape and having first and second electrodes (8, 6) attached thereto, said piezoelectric layer (2) being attached to a cell member (3), said electrodes (8, 6) being electrically connected to an electrical circuit including a switching element;

providing an acoustic wave for impinging on said piezoelectric layer (2), said acoustic wave having a reflected portion; and

modulating said reflected portion of said acoustic wave by controlling the mechanical impedance of said piezoelectric layer (2), said controlling being effected by switching said switching element at a frequency which equals the frequency of a message signal arriving from an electronic component,

the resonance frequency being determined by the physical dimensions of said transducer element, wherein the wavelength of the external acoustic field is substantially larger than the physical dimensions of said transducer element.

41. The method of claim 40, wherein said electronic component is a sensor.

42. The method of claim 40, further comprising:

providing third and fourth electrodes (8b, 6b) attached to said piezoelectric layer (2), said third and fourth electrodes (8b, 6b) being electrically connected to said electrical circuit; and
changing the electrical connections between said electrodes (8a, 8b, 6a, 6b) by means of said switching element so as to change the mechanical impedance of said piezoelectric layer (2).

43. The method of claim 40, wherein said first and second electrodes (8a, 6a) are attached to a first cell member (3a) and said third and fourth electrodes (8b, 6b) are attached to a second cell member (3b).

44. The method of claim 40, wherein said electronic component is a resistor.

45. The transducer element of claim 1, wherein said transducer is used as a sensor.

Patentansprüche

1. Wandlerelement (1) zum Umwandeln von durch ein externes Fluidmedium übertragener akustischer Energie in elektrische Energie, welches aufweist:

ein Zellenteil (3) mit einem Hohlraum (4),
eine im Wesentlichen flexible piezoelektrische Schicht (2) mit einer konkaven Form, die peripher an dem Zellenteil (3) so angebracht ist, dass sie den Hohlraum (4) gegenüber dem externen Fluidmedium isoliert, und derart, dass ein mittlerer Bereich der flexiblen piezoelektrischen Schicht (2) nicht gestützt wird und frei über dem Hohlraum (4) schwimmt,
welche piezoelektrische Schicht (2) eine externe Oberfläche und eine interne Oberfläche hat, wobei die piezoelektrische Schicht (2) solche Abmessungen zeigt, um Schwankungen hiervon in den und aus dem Hohlraum (4) bei ihrer Resonanzfrequenz beim Auftreffen eines externen, durch das externe Fluidmedium übertragenen akustischen Feldes zu ermöglichen, und
eine erste Elektrode (8), die an der externen Oberfläche angebracht ist, und eine zweite Elektrode (6), die an der internen Oberfläche angebracht ist,

wobei die Resonanzfrequenz durch die körperlichen Abmessungen des Wandlerelements (1) bestimmt ist und die Wellenlänge des externen akustischen Feldes wesentlich größer als die körperlichen Abmessungen des Wandlerelements (1) ist.

2. Wandlerelement nach Anspruch 1, bei dem der Hohlraum (4) in ein Substrat (11, 12) geätzt ist.

3. Wandlerelement nach Anspruch 2, bei dem das Substrat (11, 12) eine elektrisch isolierende Schicht (12) und eine elektrisch leitende Schicht (11) enthält.

4. Wandlerelement nach Anspruch 3, bei dem die erste Elektrode (8) einteilig mit einer im Wesentlichen dünnen, elektrisch leitenden Schicht, die sich auf dem Substrat (11, 12) befindet, ausgebildet ist.

5. Wandlerelement nach Anspruch 4, bei dem die im Wesentlichen dünne, elektrisch leitende Schicht (11) mittels einer Abdichtverbindung (16) mit dem Substrat verbunden ist.

6. Wandlerelement nach Anspruch 3, bei dem die elektrisch isolierende Schicht (12) aus Silizium besteht.

7. Wandlerelement nach Anspruch 3, bei dem die elektrisch isolierende Schicht (12) aus einem Polymermaterial besteht.

8. Wandlerelement nach Anspruch 5, bei dem die Abdichtverbindung (16) aus Indium besteht.

9. Wandlerelement nach Anspruch 1, bei dem die piezoelektrische Schicht (2) aus PVDF besteht.

10. Wandlerelement nach Anspruch 1, bei dem der Hohlraum (4) im Querschnitt kreisförmig ist.

11. Wandlerelement nach Anspruch 1, bei dem der Hohlraum (4) im Querschnitt hexagonal ist.

12. Wandlerelement nach Anspruch 2, bei dem das Substrat (11, 12) mehrere Zellenteile enthält.

13. Wandlerelement nach Anspruch 1, bei dem zumindest eine von der ersten und der zweiten Elektrode (8, 6) besonders geformt ist, um ein maximales elektrisches Ausgangssignal zu liefern.

14. Wandlerelement nach Anspruch 13, bei dem das elektrische Ausgangssignal ein Strom ist.

15. Wandlerelement nach Anspruch 13, bei dem das elektrische Ausgangssignal eine Spannung ist.

16. Wandlerelement nach Anspruch 13, bei dem das elektrische Ausgangssignal eine Leistung ist.

17. Wandlerelement nach Anspruch 13, bei dem zumindest eine der Elektroden (8, 6) einen ersten und einen zweiten Elektrodenbereich (80a, 80b) aufweist, die durch ein Verbindungsteil (82) miteinander verbunden sind.

18. Wandlerelement nach Anspruch 1, bei dem der Hohlraum (4) Gas enthält.

19. Wandlerelement nach Anspruch 18, bei dem das Gas einen im Wesentlichen niedrigen Druck hat.

20. Wandlerelement nach Anspruch 19, bei dem das Wandlerelement (1) als ein Sender verwendet wird.

21. Wandlerelement nach Anspruch 19, weiterhin enthaltend ein Schaltelement, das elektrisch damit verbunden ist, um die mechanische Impedanz der piezoelektrischen Schicht (2) gesteuert zu ändern.

22. Wandlerelement nach Anspruch 1, bei dem zumindest eine von der ersten Elektrode (8) und der zweiten Elektrode (6) einen ersten Bereich (80a) und einen zweiten Bereich (80b), die sich auf der piezoelektrischen Schicht (2) befinden, enthält, wobei der erste und der zweite Bereich (80a, 80b) durch ein Verbindungsteil (82) elektrisch verbunden sind.

23. Wandlerelement nach Anspruch 21, bei dem die Schaltfrequenz des Schaltelements gleich der Frequenz eines elektrischen Nachrichtensignals, das von einem elektronischen Teil eintrifft, ist.

24. Wandlerelement nach Anspruch 23, bei dem das elektronische Teil ein Sensor ist.

25. Wandlerelement nach Anspruch 21, bei dem das Schaltelement zum Modulieren einer reflektierten akustischen Welle gemäß einem Nachrichtensignal, das von einer elektronischen Komponente eintrifft, vorgesehen ist.

26. Wandlerelement nach Anspruch 21, weiterhin enthaltend eine dritte Elektrode (8b), die an der externen Oberfläche angebracht ist, und eine vierte Elektrode (6b), die an der internen Oberfläche angebracht ist.

27. Wandlerelement nach Anspruch 26, bei dem das Schaltelement abwechselnd die Elektroden (8a, 8b, 6a, 6b) in paralleler und antiparalleler Verbindung schaltet, wodurch die mechanische Impedanz der piezoelektrischen Schicht (2) gesteuert geändert wird.

28. Wandlerelement nach Anspruch 26, bei dem die Elektroden (8a, 8b, 6a, 6b) mittels einer im Wesentlichen eingebauten antiparallelen Verbindung elektrisch miteinander verbunden sind.

29. Wandlerelement nach Anspruch 26, bei dem die Elektroden (8a, 8b, 6a, 6b) mittels einer im Wesentlichen eingebauten parallelen Verbindung elektrisch miteinander verbunden sind.

30. Wandlerelement nach Anspruch 26, bei dem das Schaltelement ein Ein/Aus-Schalter ist.

31. Wandlerelement nach Anspruch 26, bei dem die piezoelektrische Schicht (2) einen ersten und einen zweiten Bereich (2a, 2b) mit entgegengesetzten Polaritäten enthält.

32. Wandlerelement nach Anspruch 20, bei dem das Senderelement zwei Zellenteile (3a, 3b) enthält.

33. Wandlerelement nach Anspruch 32, bei dem die zwei Zellenteile (3a, 3b) mittels einer im Wesentlichen eingebauten parallelen Verbindung elektrisch miteinander verbunden sind.

34. Wandlerelement nach Anspruch 32, bei dem die zwei Zellenteile (3a, 3b) mittels einer im Wesentlichen eingebauten antiparallelen Verbindung miteinander verbunden sind.

35. Wandlerelement nach Anspruch 32, bei dem das Schaltelement abwechselnd die Zellenteile (3a, 3b) in paralleler und antiparalleler Schaltung verbindet.

36. Wandlerelement nach Anspruch 32, bei dem die Zellenteile (3a, 3b) piezoelektrische Schichten (2a, 2b) mit entgegengesetzten Polaritäten haben.

37. Wandlerelement nach Anspruch 19, bei dem der Hohlraum von einer piezoelektrischen Zweifaltenschicht (50a, 50b) enthaltend eine obere Schicht (50a), die auf einer unteren Schicht (50b) angeordnet ist, bedeckt ist.

38. Wandlerelement nach Anspruch 37, bei dem die obere und die untere Schicht (50a, 50b) entgegengesetzte Polaritäten aufweisen.

39. Wandlerelement nach Anspruch 37, weiterhin enthaltend eine isolierende Schicht (52), die sich zwischen der oberen und unteren Schicht (50a, 50b) befindet.

40. Verfahren zum Senden einer akustischen Information, welches aufweist:

Vorsehen einer im Wesentlichen flexiblen piezoelektrischen Schicht (2) mit einer konkaven Form und mit einer ersten und einer zweiten Elektrode (8, 6), die daran befestigt sind, welche piezoelektrische Schicht (2) an einem Zellenteil (3) angebracht ist, wobei die Elektroden (8, 6) mit einer elektrischen Schaltung enthaltend ein Schaltelement elektrisch verbunden sind; Vorsehen einer akustischen Welle zum Auftreffen auf die piezoelektrische Schicht (2), wobei die akustische Welle einen reflektierten Teil hat; und
Modulieren des reflektierten Teils der akustischen Welle durch Steuern der mechanischen Impedanz der piezoelektrischen Schicht (2), wobei das Steuern durch Schalten des Schaltelements bei einer Frequenz, die gleich der Frequenz eines Nachrichtensignals, das von einer elektronischen Komponente eintrifft, ist, bewirkt wird, die Resonanzfrequenz bestimmt wird durch körperliche Abmessungen des Wandlerelements, wobei die Wellenlänge des externen akustischen Feldes wesentlich größer als die körperlichen Abmessungen des Wandlerelements ist.

41. Verfahren nach Anspruch 40, bei dem die elektronische Komponente ein Sensor ist.

42. Verfahren nach Anspruch 40, weiterhin aufweisend:

Vorsehen einer dritten und vierten Elektrode (8b, 6b), die an der piezoelektrischen Schicht (2) angebracht sind, wobei die dritte und die vierte Elektrode (8b, 6b) mit der elektrischen Schaltung elektrisch verbunden sind; und
Ändern der elektrischen Verbindungen zwischen den Elektroden (8a, 8b, 6a, 6b) mittels des Schaltelements derart, dass die mechanische Impedanz der piezoelektrischen Schicht (2) geändert wird.

43. Verfahren nach Anspruch 40, bei dem die erste und die zweite Elektrode (8a, 6a) an einem ersten Zellenteil (3a) angebracht sind und die dritte und vierte Elektrode (8b, 6b) an einem zweiten Zellenteil (3b) angebracht sind.

44. Verfahren nach Anspruch 40, bei dem die elektronische Komponente ein Widerstand ist.

45. Wanderelement nach Anspruch 1, bei dem der Wandler als ein Sensor verwendet wird.

Revendications

1. Élément de transducteur (1) destiné à convertir une énergie acoustique transmise par l'intermédiaire d'un milieu fluide extérieur en une énergie électrique comprenant :

un élément de cellule (3) qui présente une cavité (4);

une couche piézo-électrique sensiblement flexible (2) qui présente une forme concave et qui est fixée de manière périphérique sur ledit élément de cellule (3) de manière à isoler ladite cavité (4) du milieu fluide extérieur, et de telle sorte qu'une partie centrale de ladite couche piézo-électrique flexible (2) ne soit pas supportée et flotte librement au-dessus de ladite cavité (4) ;
ladite couche piézo-électrique (2) présentant une surface extérieure et une surface intérieure, ladite couche piézo-électrique (2) étant **caractérisée par** des dimensions qui permettent des fluctuations de celle-ci dans et hors de ladite cavité (4) à sa fréquence de résonance lorsqu'elle est affectée par un champ acoustique extérieur transmis par l'intermédiaire du milieu fluide extérieur ; et
une première électrode (8) fixée sur ladite surface extérieure et une deuxième électrode (6) fixée sur ladite surface intérieure ;
la fréquence de résonance étant déterminée par les dimensions physiques dudit élément de transducteur (1), dans lequel la longueur d'onde du champ acoustique extérieur est sensiblement plus grande que les dimensions physiques dudit élément de transducteur (1).

2. Élément de transducteur selon la revendication 1, dans lequel ladite cavité (4) est gravée de manière chimique dans un substrat (11, 12).

3. Élément de transducteur selon la revendication 2, dans lequel ledit substrat (11, 12) comprend une couche isolante de manière électrique (12) et une couche conductrice de manière électrique (11).

4. Élément de transducteur selon la revendication 3, dans lequel ladite première électrode (8) est réalisée d'une pièce avec une couche conductrice de manière électrique sensiblement mince disposée sur ledit substrat (11, 12).

5. Élément de transducteur selon la revendication 4, dans lequel ladite couche conductrice de manière électrique sensiblement mince (11) est connectée audit substrat au moyen d'une connexion d'étanchéité (16).

6. Élément de transducteur selon la revendication 3, dans lequel ladite couche isolante de manière électrique (12) est réalisée en silicium.

7. Élément de transducteur selon la revendication 3, dans lequel ladite couche isolante de manière électrique (12) est réalisée dans un matériau polymère.

8. Élément de transducteur selon la revendication 5, dans lequel ladite connexion d'étanchéité (16) est réalisée en indium.

9. Élément de transducteur selon la revendication 1, dans lequel ladite couche piézo-électrique (2) est réalisée en PVDF.

10. Élément de transducteur selon la revendication 1, dans lequel ladite cavité (4) présente une section transversale circulaire.

11. Élément de transducteur selon la revendication 1, dans lequel ladite cavité (4) présente une section transversale hexagonale.

12. Élément de transducteur selon la revendication 2, dans lequel ledit substrat (11, 12) comprend une pluralité d'éléments de cellules.

13. Élément de transducteur selon la revendication 1, dans lequel l'une au moins desdites première et deuxième électrodes (8, 6) présente une forme spécifique de manière à fournir une sortie électrique maximale.

14. Élément de transducteur selon la revendication 13, dans lequel ladite sortie électrique est un courant.

15. Élément de transducteur selon la revendication 13, dans lequel ladite sortie électrique est une tension.

16. Élément de transducteur selon la revendication 13, dans lequel ladite sortie électrique est une puissance.

17. Élément de transducteur selon la revendication 13, dans lequel l'une au moins desdites électrodes (8, 6) est **caractérisée par** des première et deuxième parties d'électrode (80a, 80b) interconnectées par un élément de connexion (82).

18. Élément de transducteur selon la revendication 1, dans lequel ladite cavité (4) comprend un gaz.

19. Élément de transducteur selon la revendication 18, dans lequel ledit gaz présente une pression sensiblement basse.

20. Élément de transducteur selon la revendication 19, dans lequel ledit élément de transducteur (1) est utilisé en tant qu'émetteur.

21. Élément de transducteur selon la revendication 19, comprenant en outre un élément de commutation connecté de manière électrique à celui-ci de façon à modifier de manière pouvant être commandée l'impédance mécanique de ladite couche piézo-électrique (2).

22. Élément de transducteur selon la revendication 1, dans lequel l'une au moins de la première électrode (8) et de la deuxième électrode (6) comprend une première partie (80a) et une deuxième partie (80b) disposées sur la couche piézo-électrique (2), dans lequel les première et deuxième parties (80a, 80b) sont connectées de manière électrique par un élément de connexion (82).

23. Élément de transducteur selon la revendication 21, dans lequel la fréquence de commutation dudit élément de commutation est égale à la fréquence d'un signal de message électrique qui arrive en provenance d'un élément électronique.

24. Élément de transducteur selon la revendication 23, dans lequel ledit élément électronique est un capteur.

25. Élément de transducteur selon la revendication 21, dans lequel ledit élément de commutation sert à moduler une onde acoustique réfléchie selon un signal de message qui arrive en provenance d'un composant électronique.

26. Élément de transducteur selon la revendication 21, comprenant en outre une troisième électrode (8b) fixée sur ladite surface extérieure et une quatrième électrode (6b) fixée sur ladite surface intérieure.

27. Élément de transducteur selon la revendication 26, dans lequel ledit élément de commutation connecte alternativement lesdites électrodes (8a, 8b, 6a, 6b) selon des connexions parallèles et antiparallèles, en modifiant de ce fait de manière pouvant être commandée l'impédance mécanique de ladite couche piézo-électrique (2).

28. Élément de transducteur selon la revendication 26, dans lequel lesdites électrodes (8a, 8b, 6a, 6b) sont interconnectées de manière électrique au moyen d'une connexion antiparallèle sensiblement intégrée.

29. Élément de transducteur selon la revendication 26, dans lequel lesdites électrodes (8a, 8b, 6a, 6b) sont interconnectées de manière électrique au moyen d'une connexion parallèle sensiblement intégrée.

30. Élément de transducteur selon la revendication 26, dans lequel ledit élément de commutation est un commutateur marche / arrêt.

31. Élément de transducteur selon la revendication 26, dans lequel ladite couche piézo-électrique (2) comprend des première et deuxième parties (2a, 2b) qui présentent des polarités opposées.

32. Élément de transducteur selon la revendication 20, dans lequel ledit élément d'émetteur comprend deux éléments de cellules (3a, 3b).

33. Élément de transducteur selon la revendication 32, dans lequel lesdits deux éléments de cellules (3a, 3b) sont interconnectés de manière électrique au moyen d'une connexion parallèle sensiblement intégrée.

34. Élément de transducteur selon la revendication 32, dans lequel lesdits deux éléments de cellules (3a, 3b) sont interconnectés de manière électrique au moyen d'une connexion antiparallèle sensiblement intégrée.

35. Élément de transducteur selon la revendication 32, dans lequel ledit élément de commutation connecte alternativement lesdits éléments de cellules (3a, 3b) selon des connexions parallèles et antiparallèles.

36. Élément de transducteur selon la revendication 32, dans lequel lesdits éléments de cellules (3a, 3b) comprennent des couches piézo-électriques (2a, 2b) qui présentent des polarités opposées.

37. Élément de transducteur selon la revendication 19, dans lequel ladite cavité (4) est recouverte par une couche piézo-électrique à deux plis (50a, 50b) qui comprend une couche supérieure (50a) disposée sur une couche inférieure (50b).

38. Élément de transducteur selon la revendication 37, dans lequel lesdites couches supérieure et inférieure (50a, 50b) sont **caractérisées par** des polarités opposées.

39. Élément de transducteur selon la revendication 37, comprenant en outre une couche isolante (52) disposée entre lesdites couches supérieure et inférieure (50a, 50b).

40. Procédé de transmission d'informations acoustiques, comprenant les étapes consistant à :

fournir une couche piézo-électrique sensiblement flexible (2) qui présente une forme concave et qui présente des première et deuxième électrodes (8, 6) fixées sur celle-ci, ladite couche piézo-électrique (2) étant fixée sur un élément de cellule (3), lesdites électrodes (8, 6) étant connectées de manière électrique à un circuit électrique qui comprend un élément de commutation ;
fournir une onde acoustique destinée à affecter ladite couche piézo-électrique (2), ladite onde acoustique présentant une partie réfléchie ; et
moduler ladite partie réfléchie de ladite onde acoustique en commandant l'impédance mécanique de ladite couche piézo-électrique (2), ladite commande étant effectuée en commutant ledit élément de commutation à une fréquence qui est égale à la fréquence d'un signal de message qui arrive en provenance d'un composant électronique ;
la fréquence de résonance étant déterminée par les dimensions physiques dudit élément de transducteur, dans lequel la longueur d'onde du champ acoustique extérieur est sensiblement plus grande que les dimensions physiques dudit élément de transducteur.

41. Procédé selon la revendication 40, dans lequel ledit composant électronique est un capteur.

42. Procédé selon la revendication 40, comprenant en outre les étapes consistant à :

fournir des troisième et quatrième électrodes (8b, 6b) fixées sur ladite couche piézo-électrique (2), lesdites troisième et quatrième électrodes (8b, 6b) étant connectées de manière électrique audit circuit électrique ; et
modifier les connexions électriques entre lesdites électrodes (8a, 8b, 6a, 6b) au moyen dudit élément de commutation de façon à modifier l'impédance mécanique de ladite couche piézo-électrique (2).

43. Procédé selon la revendication 40, dans lequel lesdites première et deuxième électrodes (8a, 6a) sont fixées sur un premier élément de cellule (3a) et lesdites troisième et quatrième électrodes (8b, 6b) sont fixées sur un deuxième élément de cellule (3b).

44. Procédé selon la revendication 40, dans lequel ledit composant électronique est une résistance.

45. Élément de transducteur selon la revendication 1, dans lequel ledit transducteur est utilisé en tant que capteur.

FIG. 1a

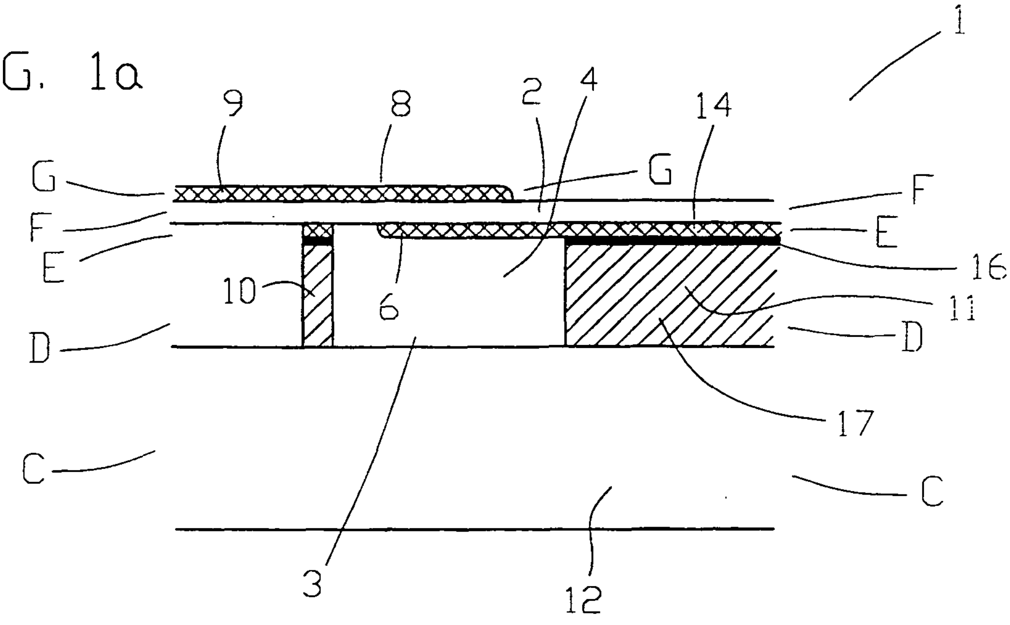

1
9
8
2
4
14
G
G
F
F
E
E
10
6
16
11
D
D
17
C
C
3
12

FIG. 1b

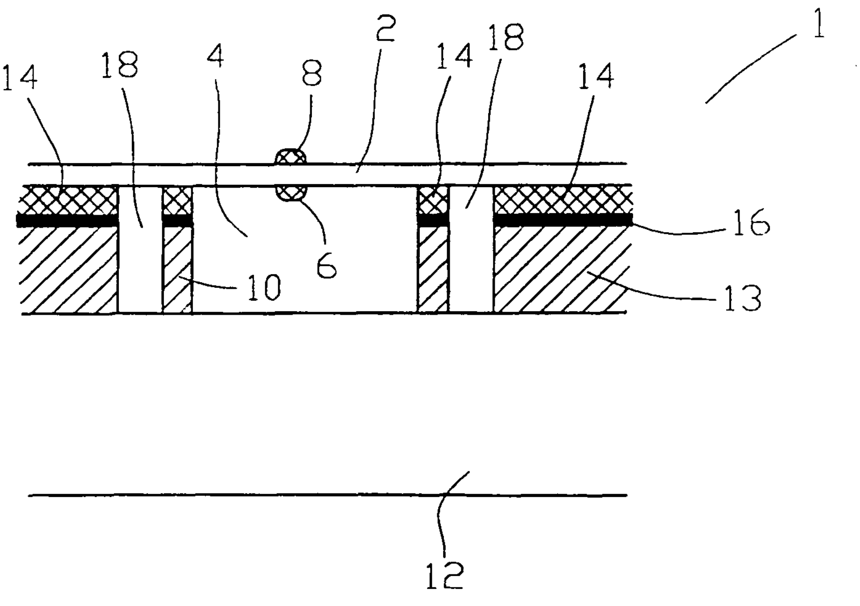

1
14
18
4
8
2
14
18
14
16
6
10
13
12

FIG. 2a

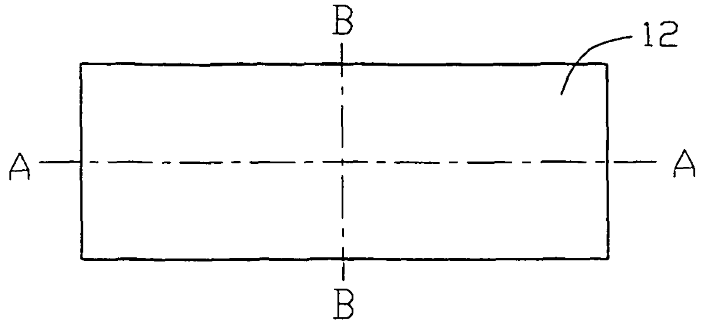


FIG. 2b

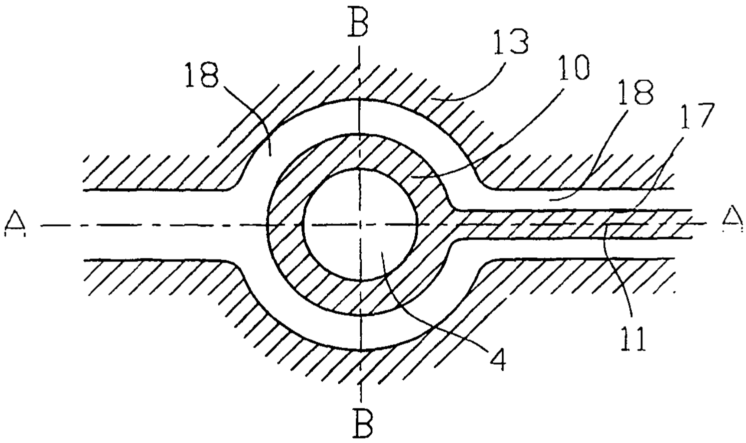


FIG. 2c

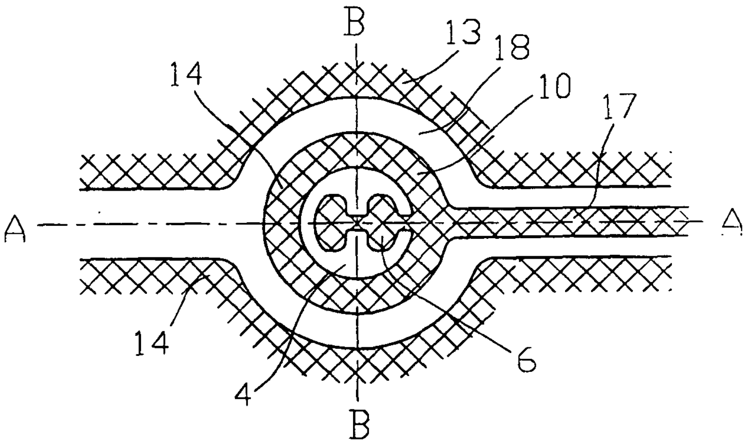


FIG. 2d

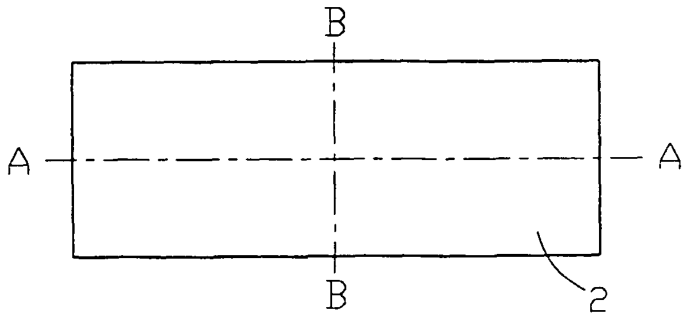


FIG. 2e

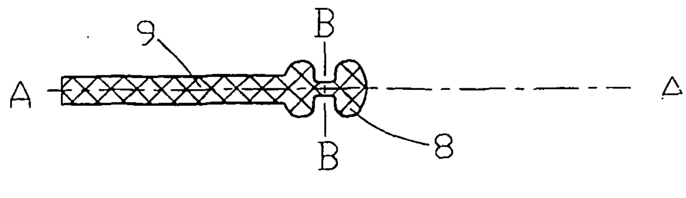


FIG. 3

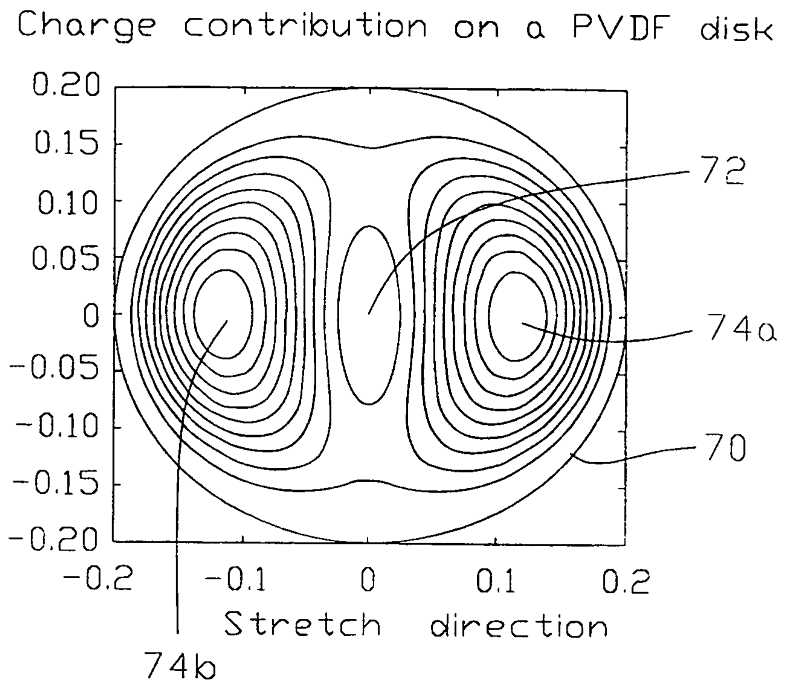


FIG. 4a

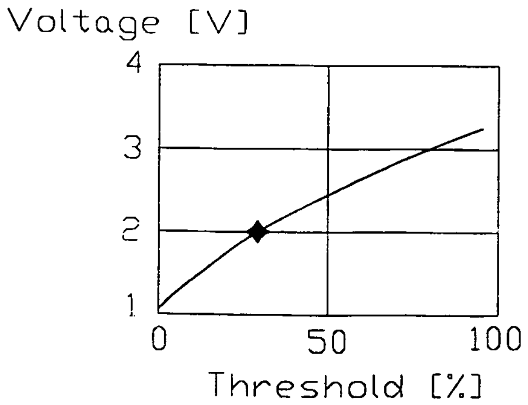


FIG. 4c

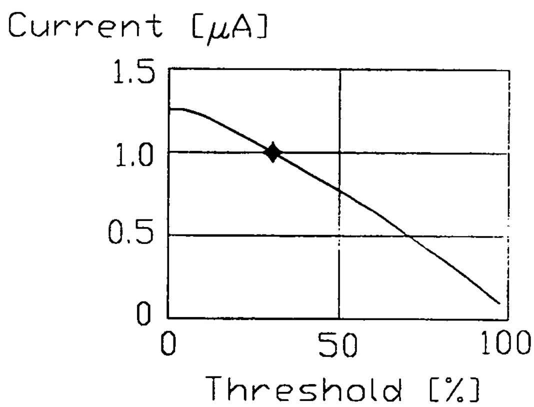


FIG. 4b

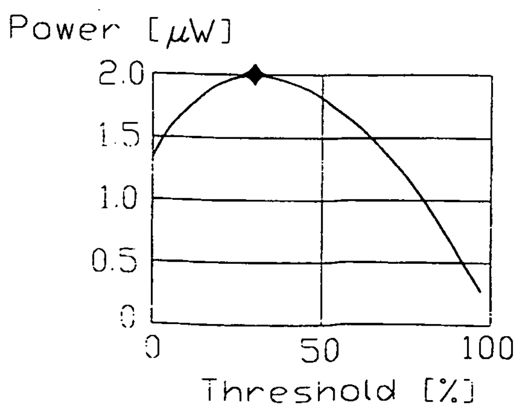


FIG. 4d

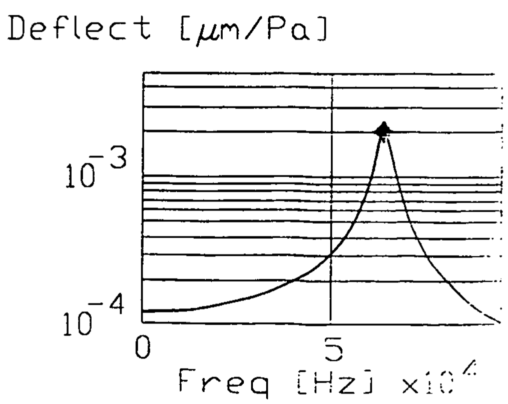


FIG. 5

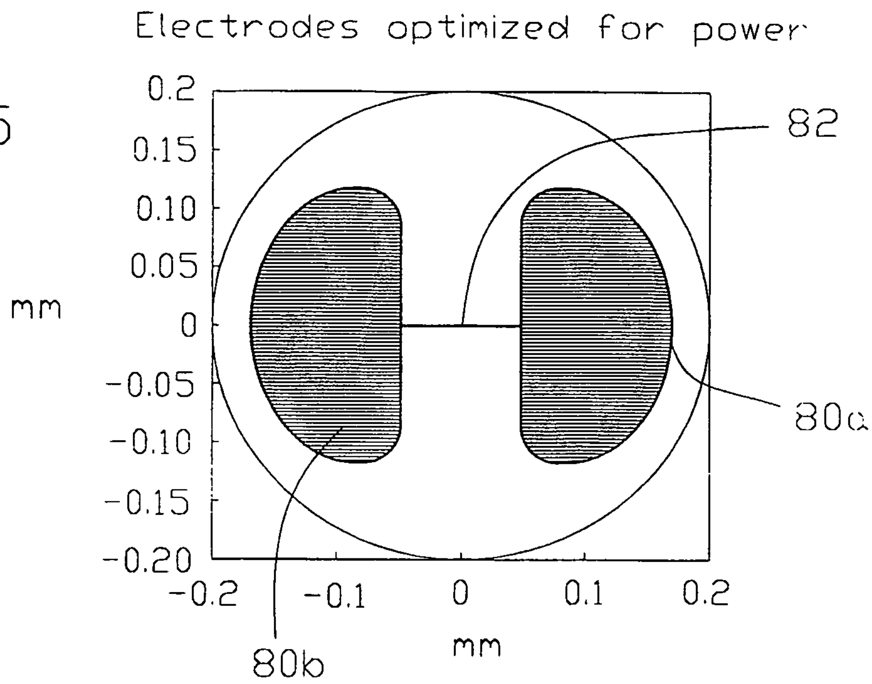

Electrodes optimized for power
0.2
0.15
0.10
0.05
0
-0.05
-0.10
-0.15
-0.20
mm
-0.2
-0.1
0
0.1
0.2
mm
82
80a
80b

FIG. 6

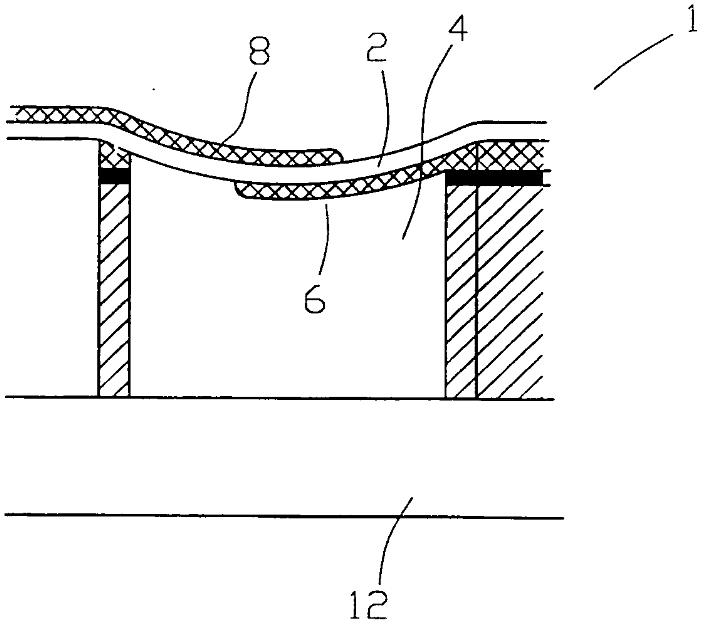

8
2
4
1
6
12

FIG. 7a

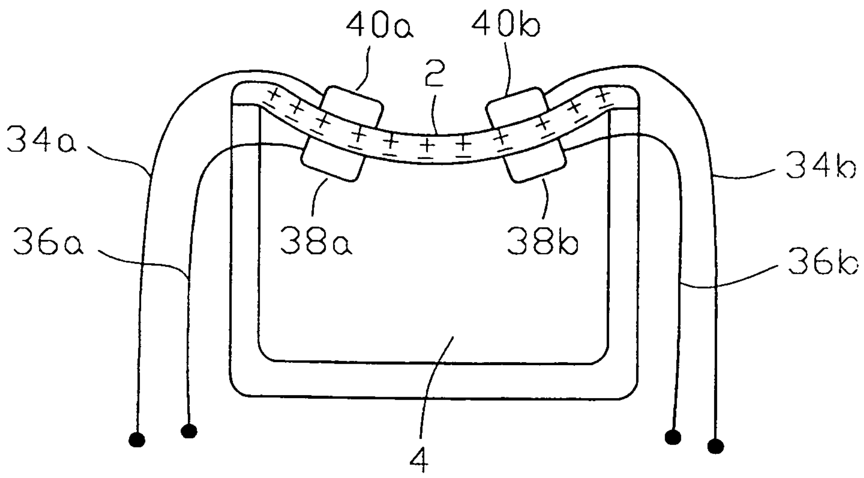


FIG. 7b

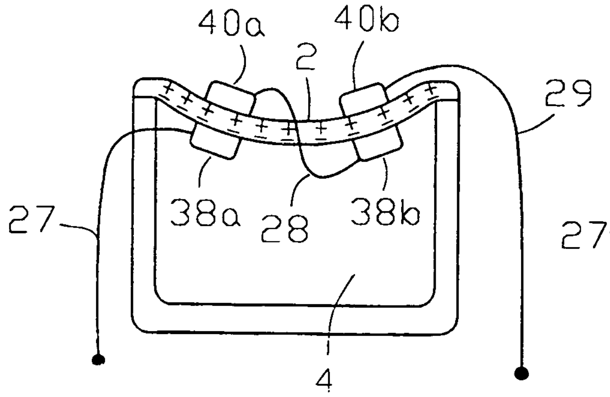


FIG. 7c

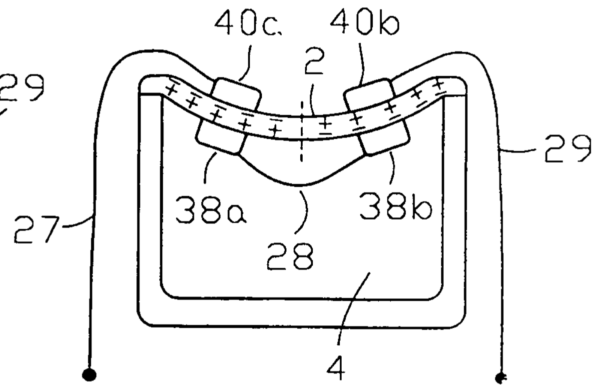


FIG. 7d

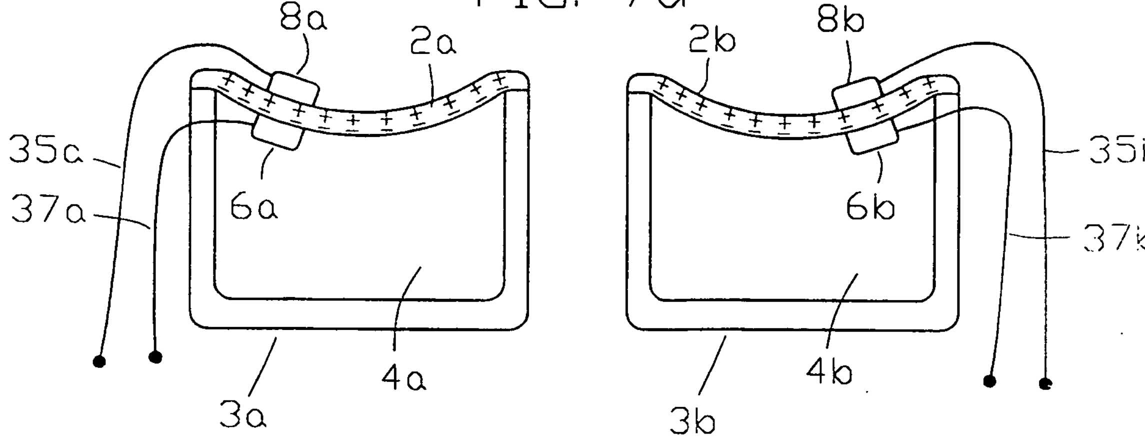


FIG. 7e

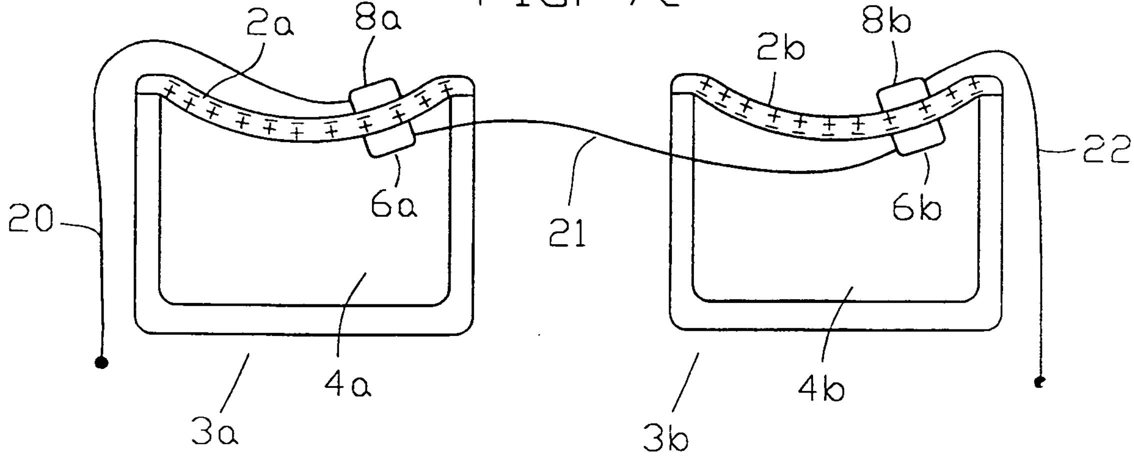


FIG. 7f

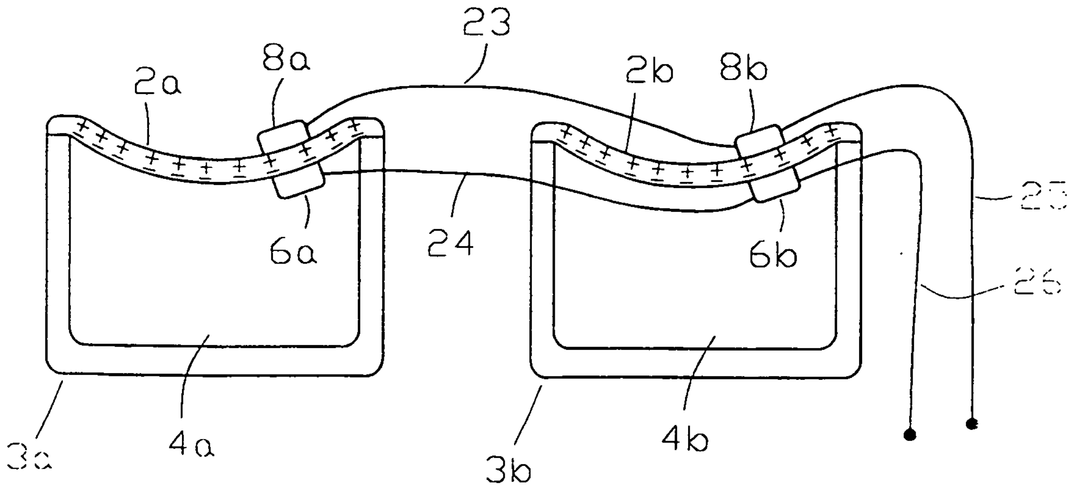


FIG. 8

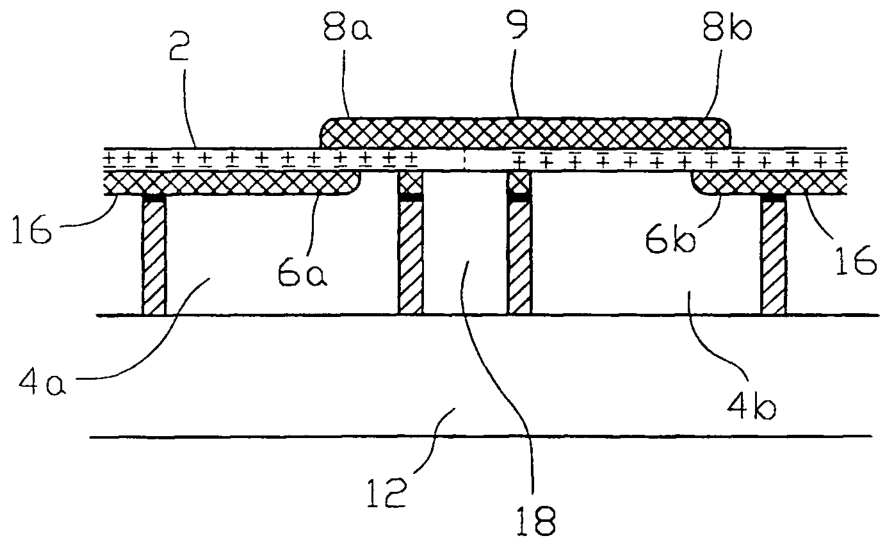
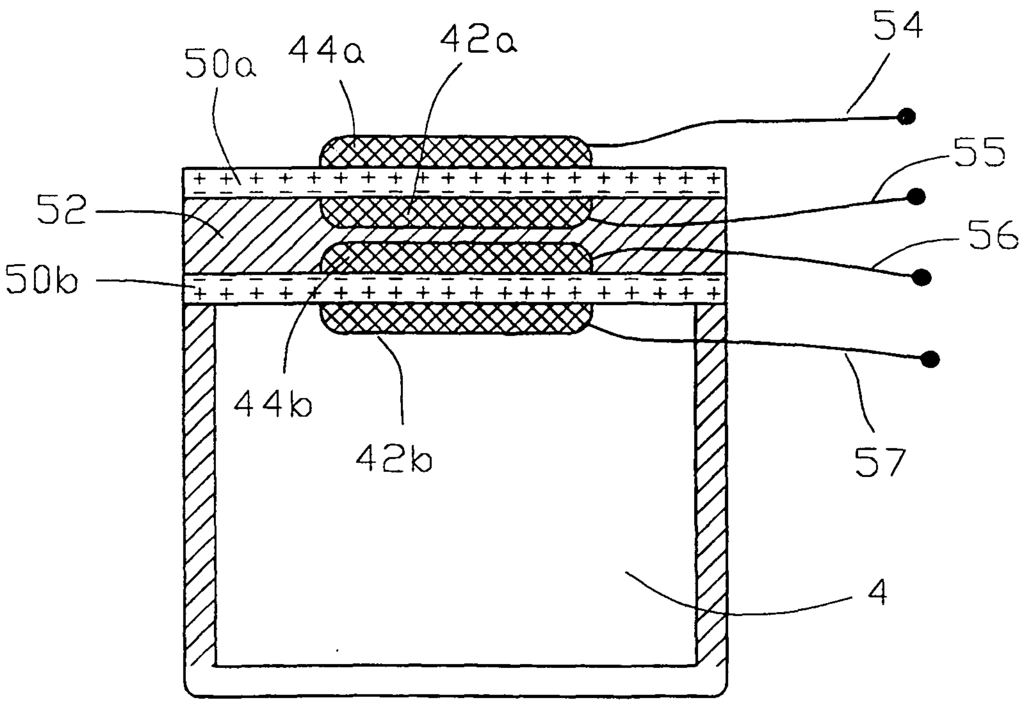

2
8a
9
8b
16
6a
6b
16
4a
4b
12
18

FIG. 9


50a
44a
42a
54
55
52
56
50b
44b
42b
57
4

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 3792204 A **[0002]**
- US 4793825 A **[0002]**
- US 3894198 A **[0002]**
- US 3798473 A **[0002]**
- US 4600855 A **[0002]**
- US 4535205 A **[0003]**
- US 4064375 A **[0004]**
- US 5160870 A **[0005]**
- US 4607145 A **[0006]**